EUV ablation

C. Liberatore1,2, A. Bartnik5, K. Mann4, M. Müller4, L. Pina2, L. Juha3, J. J. Rocca6 , A. Endo1, T. Mocek1

1 Hilase Center, Dolni Brezany, Czech Republic
2 Czech Technical University, Prague, Czech Republic
3 Institute of Physics ASCR, Prague, Czech Republic
4Laser Laboratorium Göttingen (LLG), Göttingen, Germany
5Institute of Optoelectronics (IOE) ,Military University of Technology, Warsaw, Poland
6Department of Electrical and Computer Engineering, Colorado State University, Fort Collins, USA

Fyzikální ústav
Akademie věd ČR, v. v. i.
project supported by:
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE
2007-13
OP Research and Development for Innovation

EUV generation

Neutral atoms or condensed matter cannot emit EUV radiation.

Ionization must take place first.

***Electron transition produces photon of certain energy* (EUV generation)**
***Photon can be absorbed by ions* (ionization)**

The processes of EUV generation and absorption (ionization) strongly compete against each other.

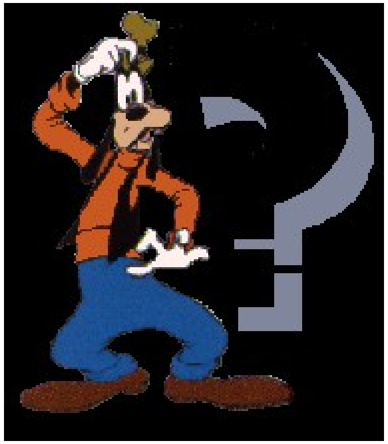
Why are we interested in EUV?

The high demand to increase the density of circuit elements on microchips brought the standard technique for printing circuits patterns to its limit.

The development of a new method named extreme ultraviolet lithography (EUVL) is further connected with development of new types of high power extreme ultraviolet (EUV) lasers.

For the development of photoresist capable of simultaneously fulfill three main requirements related to sensitivity, resolution, and line edge.

Material of interest → *Polymers*



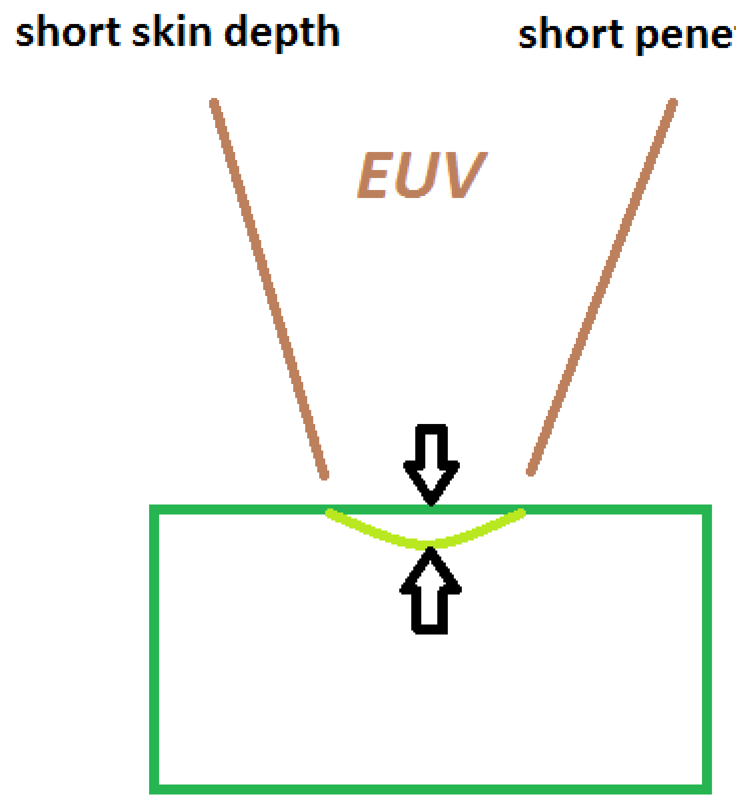
Irradiation-induced solubility changes are due to the scission of either the main polymer chain or a sensitive dissolution inhibitor inside the material; both converts into a develop-soluble group upon exposition

Characteristics of EUV ablation

Penetration

EUV are absorbed deeply in the matter with respect to current ablation

Inverse bremsstrahlung Is inefficient

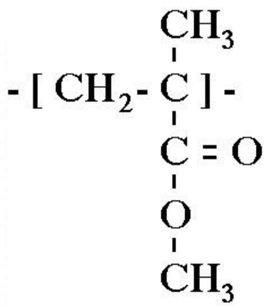


Goal of the experiment

Evaluate the advantages and disadvantages of experimental systems working at different wavelength with respect to the possibility to micro/nano structuring the polymers and as a guideline to build a more efficient EUV source

Polymers test

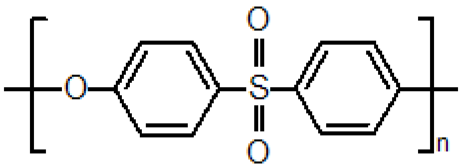
- Resistence,
- Surface recombination and nanostructuring,
- Chemical property.



PMMA

As a starting point we use PMMA.

We test the Poly(1,4-phenylene ether ether-sulfone). $\longrightarrow$ Radiation resistence higher than PMMA.

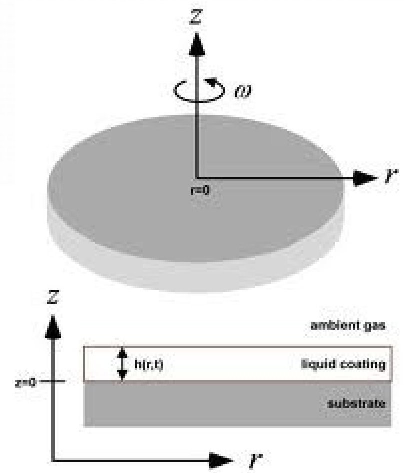


Poly(1,4-phenylene ether ether-sulfone)

Target preparation

The Poly(1,4-phenylene ether ether-sulfone) target was prepared by a ***spin coating*** processes on a silicon substrate.

Spin coating process



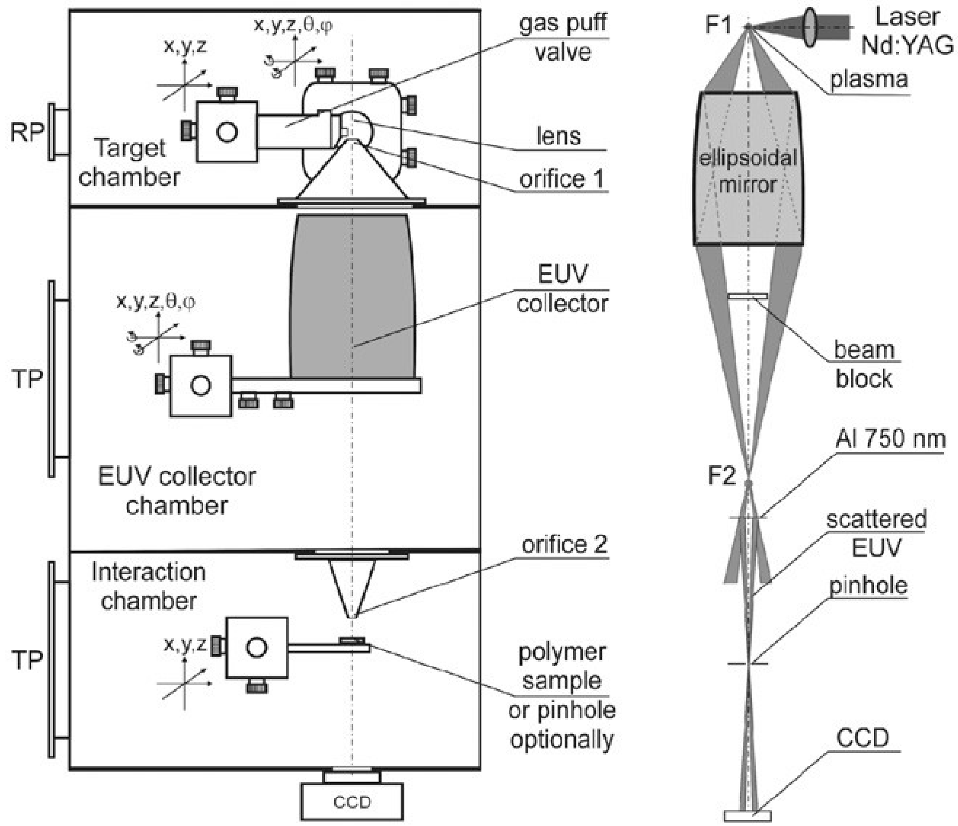
Elements affecting the properties of coated films:

- Rotational speed;
- Acceleration;
- Fume exhaust .

Critic Factor:
Repeatability.

Fyzikální ústav
Akademie věd ČR, v. v. i.
project supported by:
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE
2007-13
OP Research and Development for Innovation

Experimental system in Warsaw



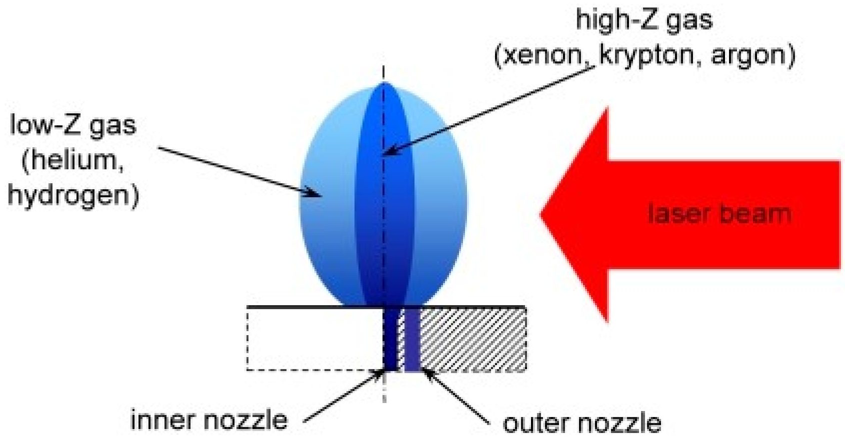
Double stream gas puff target (WAT)

Double stream gas puff target plasma source

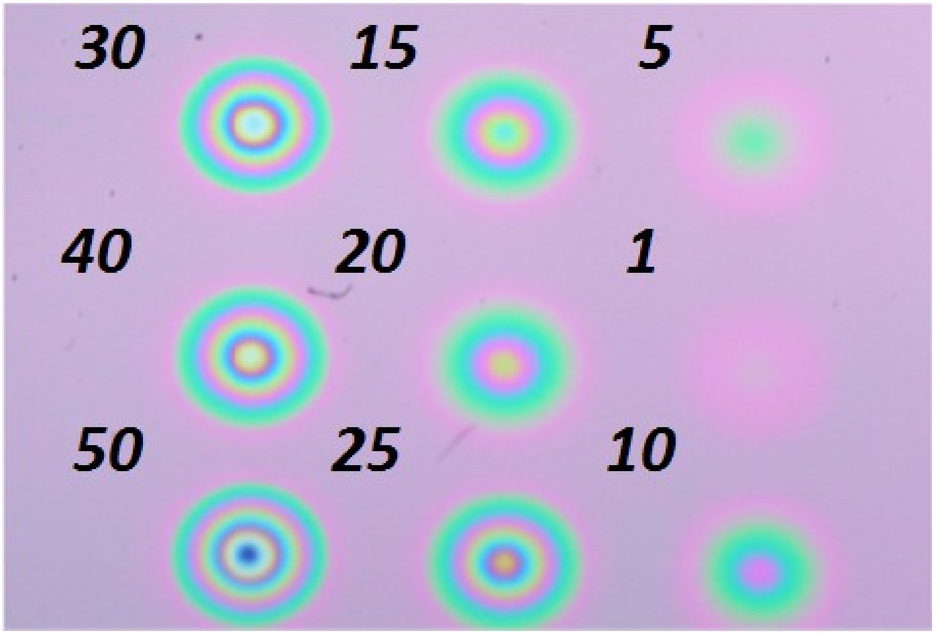
Advantages:

✓ no debris from gaseous targets
✓ compact construction, high repeatability
✓ high conversion efficiency, very robus
– thousands of shots/day

Target = Xe-Kr mixture



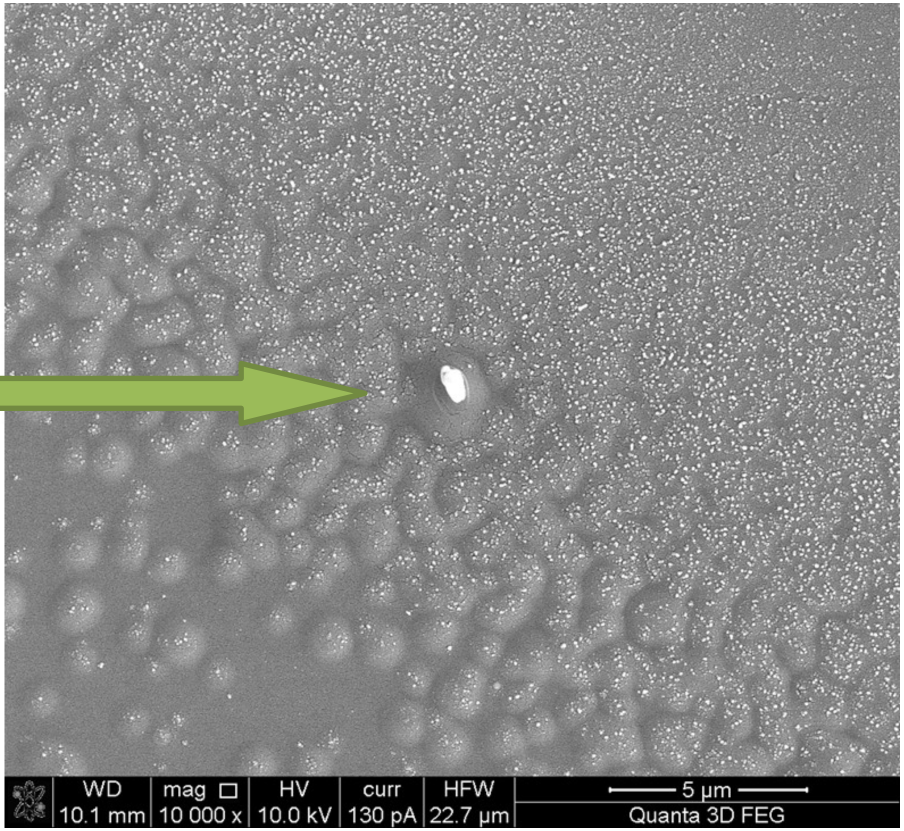
Ablation test PPEES (WAT)



Scanning electron microscope analysis (WAT)

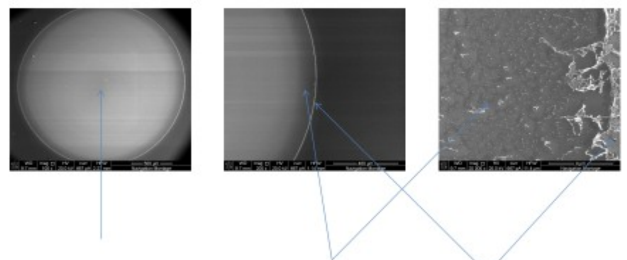
Gold coated target

Conical structure



EDS spectra

Polymer layer on Si plate irradiated with 50 EUV pulses



EDS spectrum No 1

EDS spectrum No 2

EDS spectrum No 3

EDS spectrum No 1

Only Si, polymer layer completely removed

EDS spectrum No 2

Si plus C, polymer layer partially removed

EDS spectrum No 3

Si plus C, polymer layer partially removed

Fyzikální ústav
Akademie věd ČR, v. v. i.
project supported by:
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE
2007–13
OP Research and Development for Innovation

Results

The difference between the irradiated and not irradiated part, from the point of view of the material properties is not very deep.

Chemical properties of the material are preserved.

Fyzikální ústav
Akademie věd ČR, v. v. i.
project supported by:
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE
2007-13
OP Research and Development for Innovation

Experimental system in Prague

CDL (FROM PROF. j.j.Rocca, CU, USA)

characteristics:

Dimensions: 0.4 x 0.4 m2 (0.4 x 0.8 m2 with TM pump)

Weight: 400 kg

Wavelength: 46.9 nm

Pulse length: 1.5 ns (FWHM)

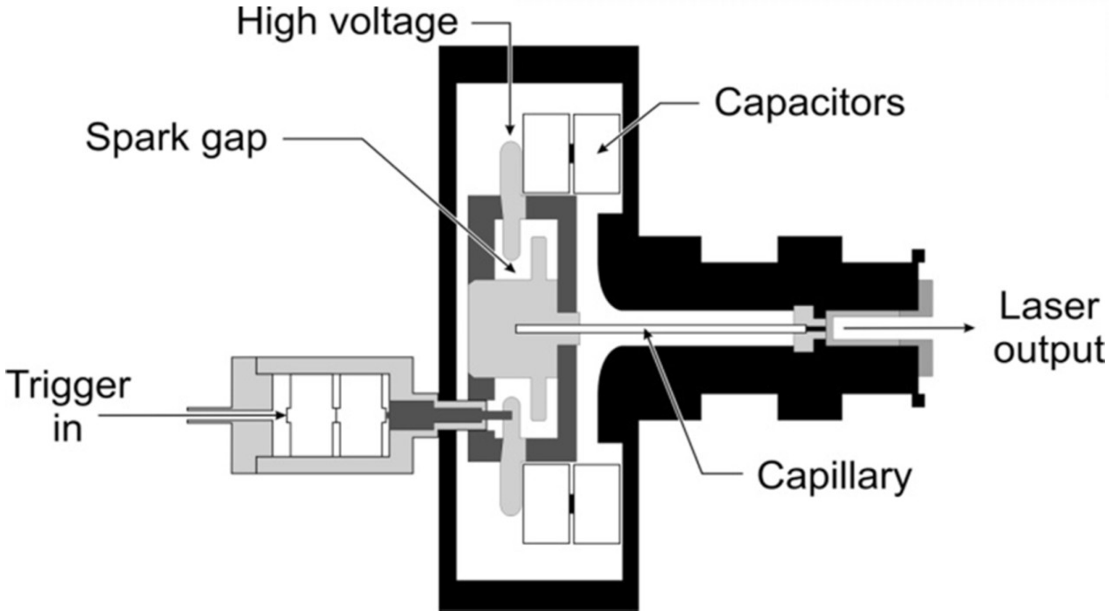
Pulse energy: > 10 mJ

Repetition rate: 5 Hz – typical, 12 Hz – maximum

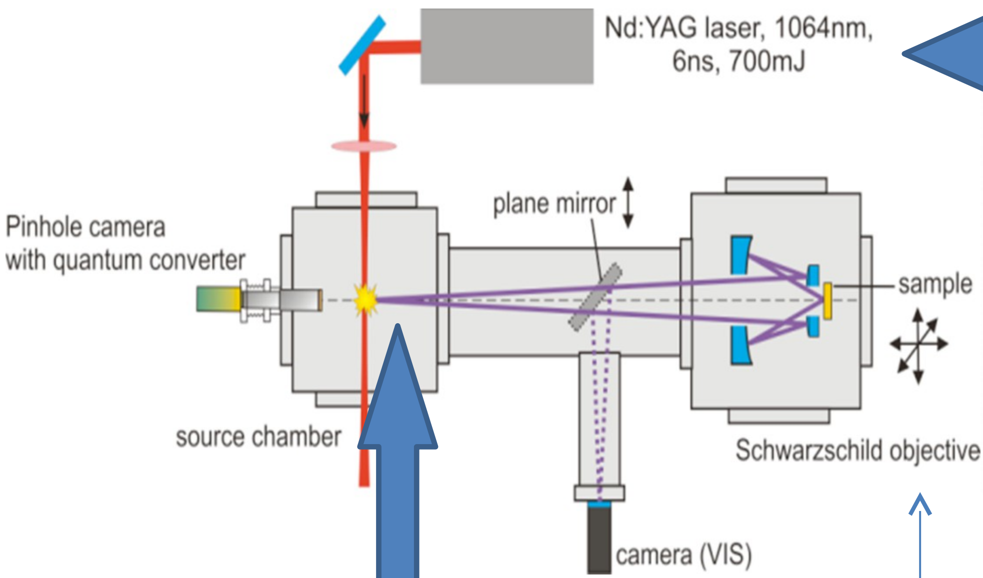
Capillary lifetime: (2-3) x 104 pulses

Current: ~21 kA

Capillary: Al2O3 (inner diameter: 3.2 mm, length 210 mm), Ar filled (50 Pa)

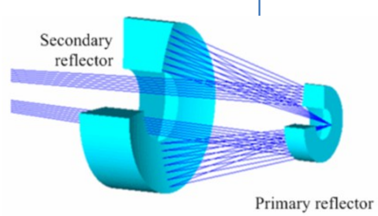


Experimental system at LLG



A new laser (1200mJ) replaced the old one allowing to increase the fluence

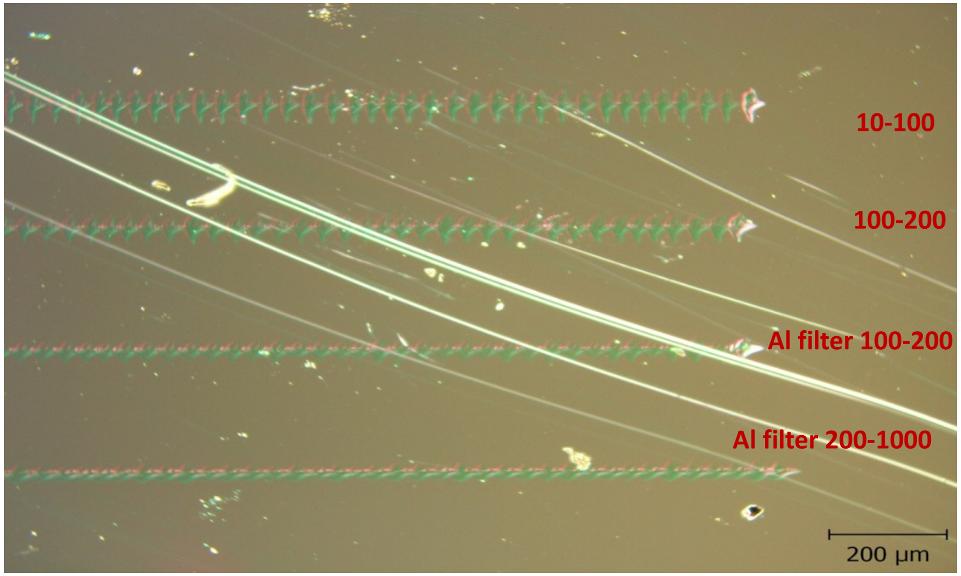
A new Schwarzschild was inserted in the system.



Characteristic:
Modified design
Mo/Si multilayer coating
Peak wavelength 13.5nm (± 2%BW)
Imaging of plasma
Micro-focus with high EUV fluence

A Xenon target replaced the old gold one → avoid mechanical problem

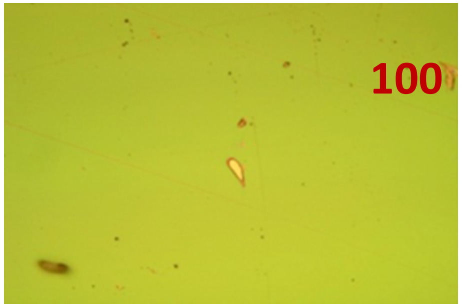
PPEES ablation test (Prague)



The possibility to ablate the poly (1,4 phenylene ether ether sulfone) by EUV was demonstrated.

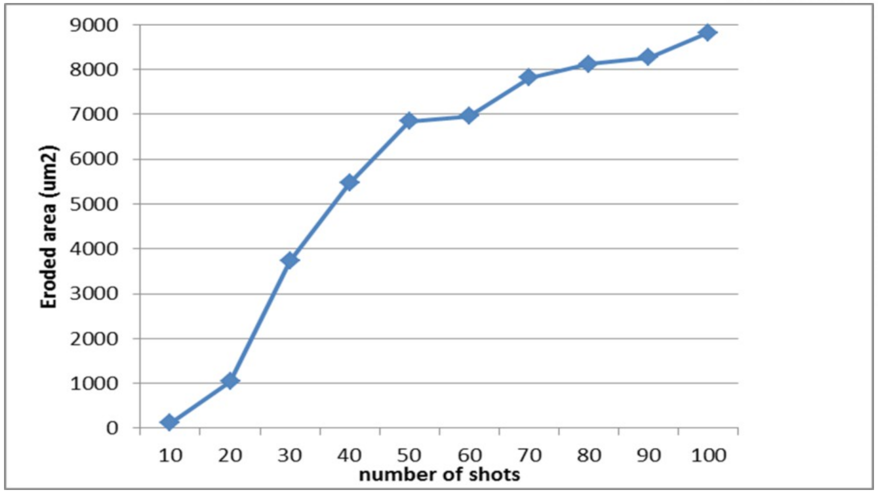
The material has very high radiation resistence and, so, it‘s interesting for future medical and industrial application.

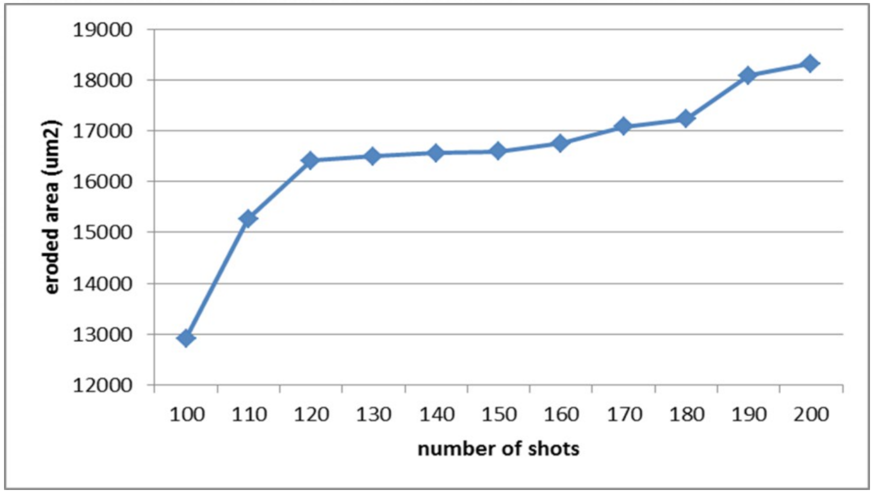
The crater structure is stable under number of shots variations and so, a well defined ablated area is selectable.



Fyzikální ústav
Akademie věd ČR, v. v. i.
project supported by:
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE
OP Research and Development for Innovation

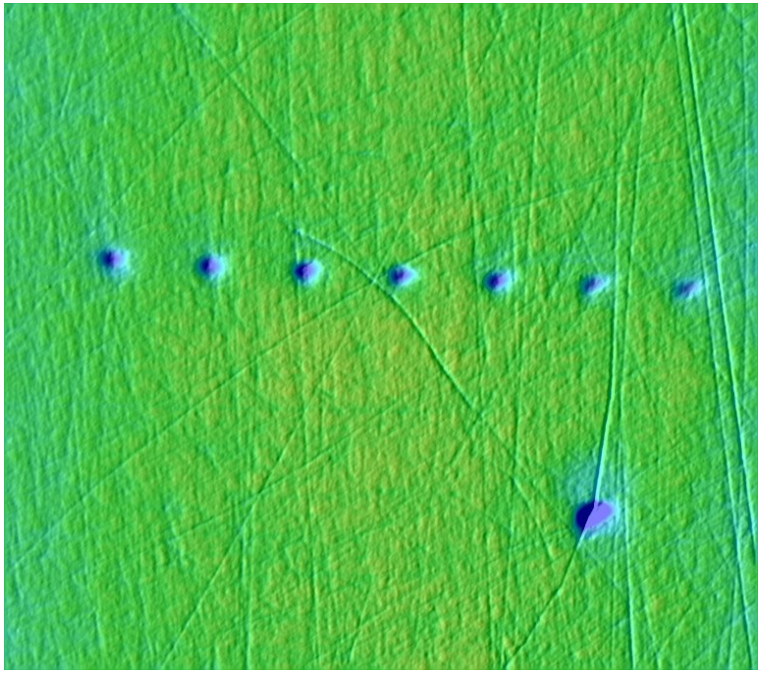
PPEES: Eroded area/number of shots (Prague)

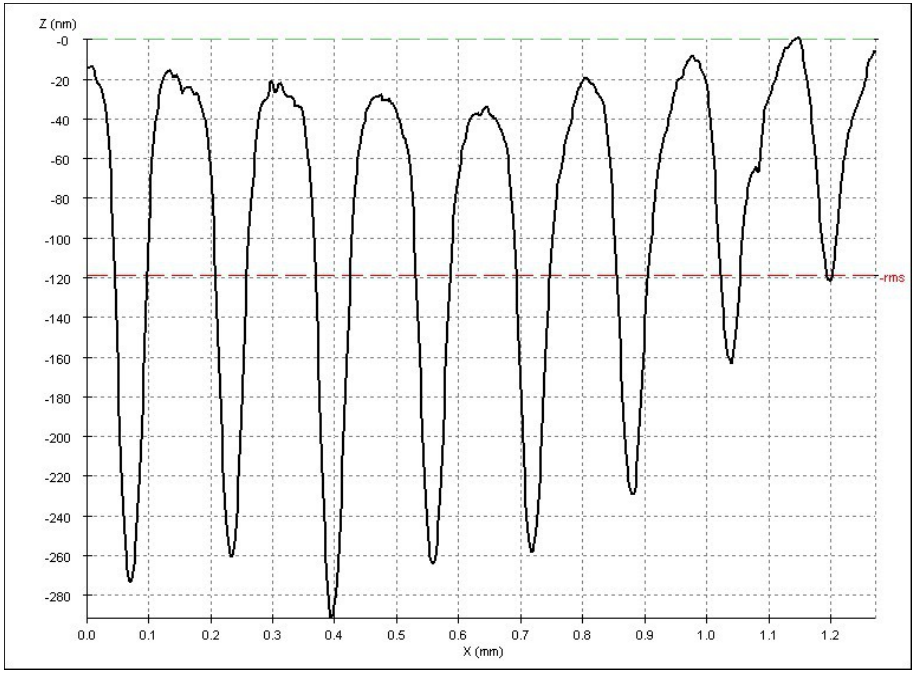




Caustic measurement on PMMA (LLG)

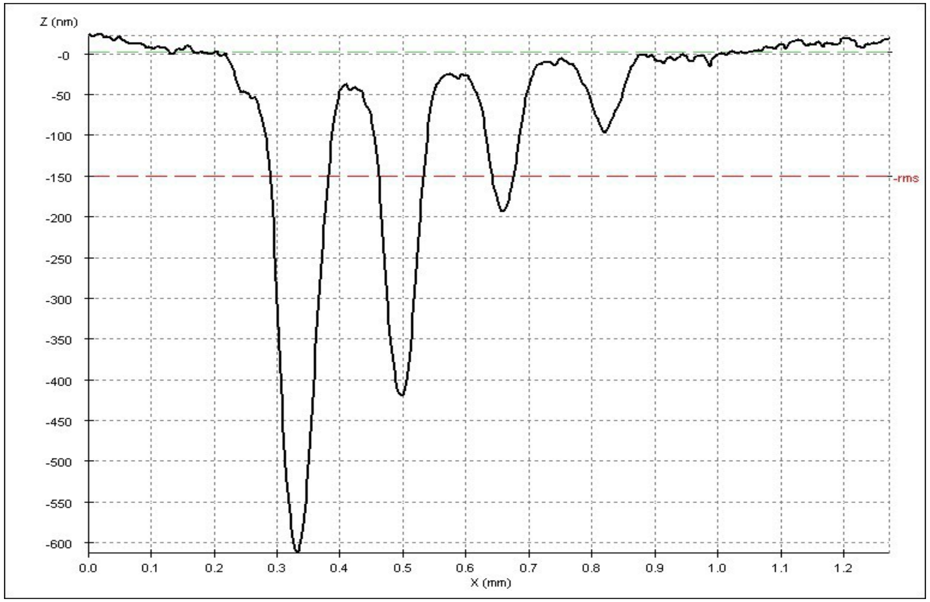
Caustic meauserent on PMMA were performed to test the stability of the system and to find a good focal position.

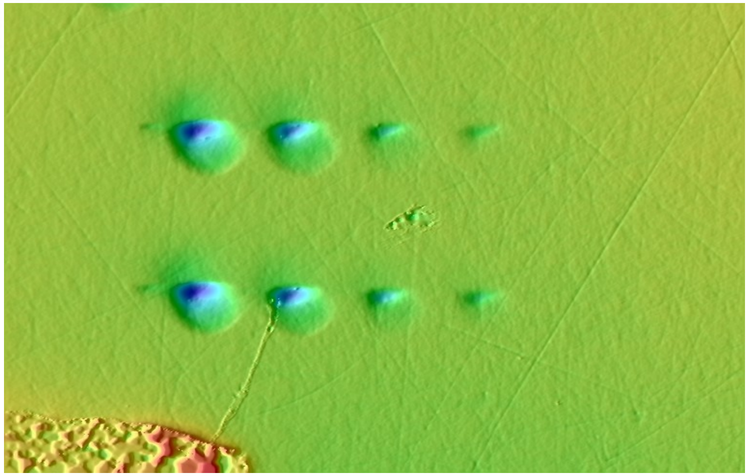




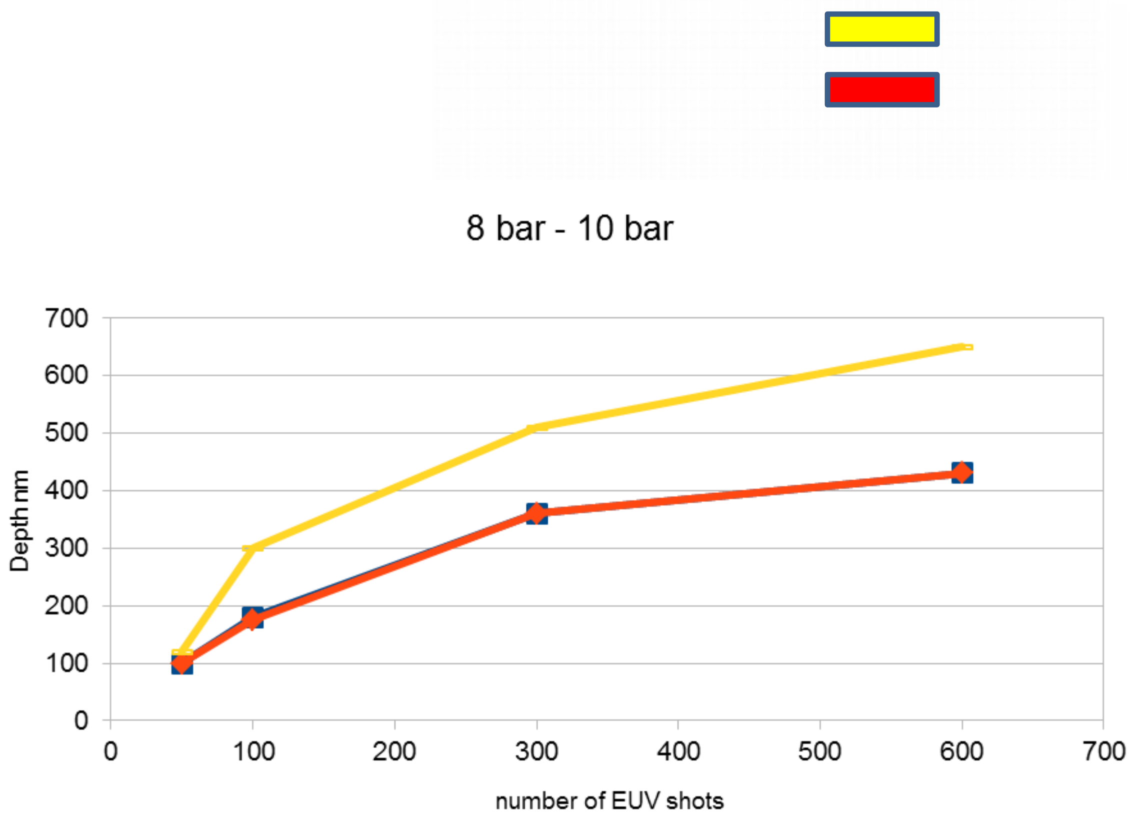
PMMA: number of shots/ablation depth (LLG)

600 – 300 – 100 – 50 shots



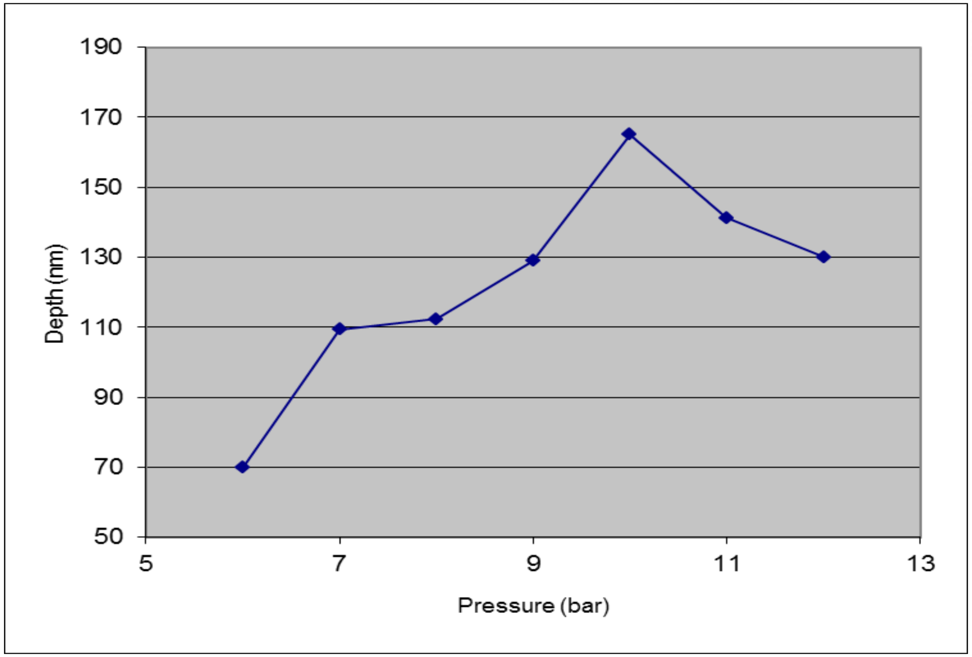


Influence of the fluence on EUV depth (LLG)



Pressure/depth measurement (LLG)

The pressure at which the maximum depth is obtained is 10bar: the efficiency of the system is increasing with pressure till the re-absorbing process becomes dominant.



Ablation test (LLG)

After focusing the focal position the working pressure 10 bar ablation tests were performed on:

- PEES;
- PI;
- Kapmon;
- Mylan.

All these materials have higher EUV radiation resistence than PMMA.

Ablation was not obtained because of too low fluence (limited by the laser and by the target used to produce the plasma).

Prague/LLG results comparison

Ablation test on PPEES was positive in Prague and negative at LLG

Explanation

PPEES has a density of about 1.24 g/cm3 and the following elemental composition C18SO4H12.

Its attenuation lengths at a wavelength of 13.5 nm (photon energy: 91.8 eV) is 215 nm.

Its attenuation length at a wavelength of 46.9 nm (photon energy: 26.4 eV) is approx. 20 nm.

Conclusions:

- *at 46.9 nm the ablation threshold should be much lower than at 13.5 nm;*
- *during the exposure at 13.5 nm, the near surface region is not so "overexposed/overheated" as in the previous case (at 46.9 nm), so that single-photon radiolytical processes would play an important role in material ablation, making visible the difference in radiation stability of PPEES and PMMA.*

Fyzikální ústav
Akademie věd ČR, v. v. i.
project supported by:
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE
2007-13
OP Research and Development for Innovation

Conclusions

Ablation was obtained in Prague and in Warsaw‘s laboratories.

Some conditions are convenient to obtain EUV ablation:

- **Non monocromacity;**
- **Long wavelength;**
- **High fluence;**
- **High density target (to create the plasma).**

References

- [1] Bowden and O'Donnell 1985, Dev. Polym. Degrad, 6 (1985) 21-61
- [2] Schnabel, W. *Polymer Degradation: Principles and Practical Applications* Macmillan Publishing Co., Inc: New York, 1981, 139, 131-135, 146-148, 95-98,100, 133-137
- [3] F.S. Daintpn, K.J. Ivin, Proc. Roy Soc. (London) A212 (1952) 96-112, and 207-220
- [4] F. Barkusky, C. Peth, A. Bayer, K. Mann, Journal of Applied Physics 101 (2007) 124908
- [5] http://www.clean.cise.columbia.edu/process/spintheory.pdf
- [6] K. Mann,F. Barkusky, A. Bayer, J.O. Dette, S. Döring, B. Flöter, P. Grossmann, U. Leinhos, M. Lübbecke, M. Reese, M. Schöneck, B. Schäfer, Laboratory-scale EUV source for metrology and Studies on material interaction
- [7] Masud Mansuripur (July 1997) "The Ronchi test," *Optics & Photonics News*, vol. 8, pages 42-46
- [8]www.smartcoater.com

Thanks

Dr Bartnik

WAT

Prof. Rocca

Dr Endo,
Dr Mocek,
Prof Pina

Prof Juha
Mr Vysin

Laser-
Laboratorium
Göttingen e.V.

Dr Mann
Mr Muller

Thank you for your attention!

Fyzikální ústav
Akademie věd ČR, v. v. i.

project supported by:

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE

2007-13
OP Research and Development for Innovation